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SUPPRESSION OF SYMPATHETIC DETONATION

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SECTION I

INTRODUCTION

In 1982, the Air Force Armament Laboratory undertook the development of an insensitive high explosive (IHE) for general purpose bombs. IHE is defined through a series of tests which reveal the explosive response to thermal, mechanical, and shock stimuli. A critical test for IHE-filled bombs requires that sympathetic detonation will not occur under normal storage configurations when a single bomb is intentionally detonated. The present pallet configuration virtually assures that sympathetic detonation between MK-80 series bombs loaded with tritonal will occur due to the close proximity of the rounds. Thus, a task was undertaken to decide how sympathetic detonation could be suppressed through either the use of barrier materials between bombs and/or the use of an alternate fill which is less sensitive than tritonal to the stimuli associated with sympathetic detonation.

During September 1983, a series of tests was conducted to observe how MK-82 bombs filled with an Air Force candidate IHE would respond to the detonation of a tritonal-filled donor (Figure 1). These experiments were conducted as a baseline and have come to be known as the "first point". The candidate IHE is called EAK, it consists of 46% ethylenediamine dinitrate, 46% ammonium nitrate, and 8% potassium nitrate. Simple expedient techniques, such as the insertion of flat plate separators, were tried to suppress sympathetic detonation (Figure 2). They were not successful. Figure 3 shows the damage done to an armor witness plate by the EAK-filled acceptor. Plate damage is characteristic of a detonation.

Following the September 1983 experiments, a series of calculations were undertaken to understand the processes involved in the sympathetic detonation phenomena. The calculational approach to the problem prohibited the

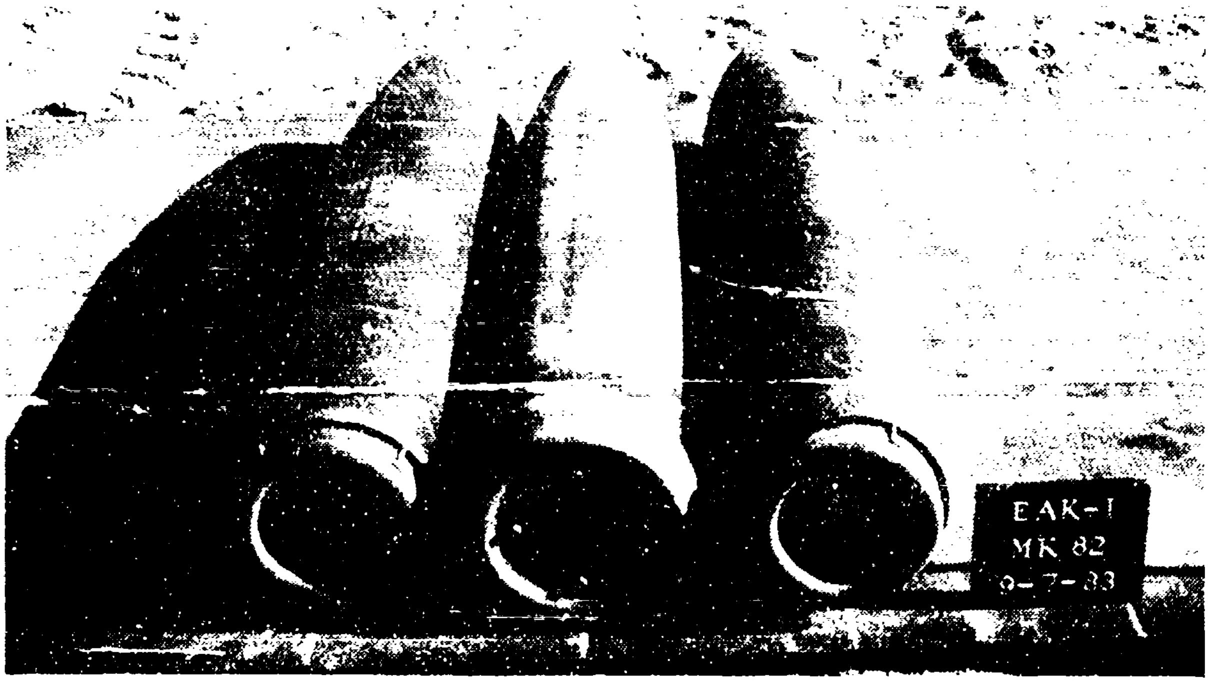
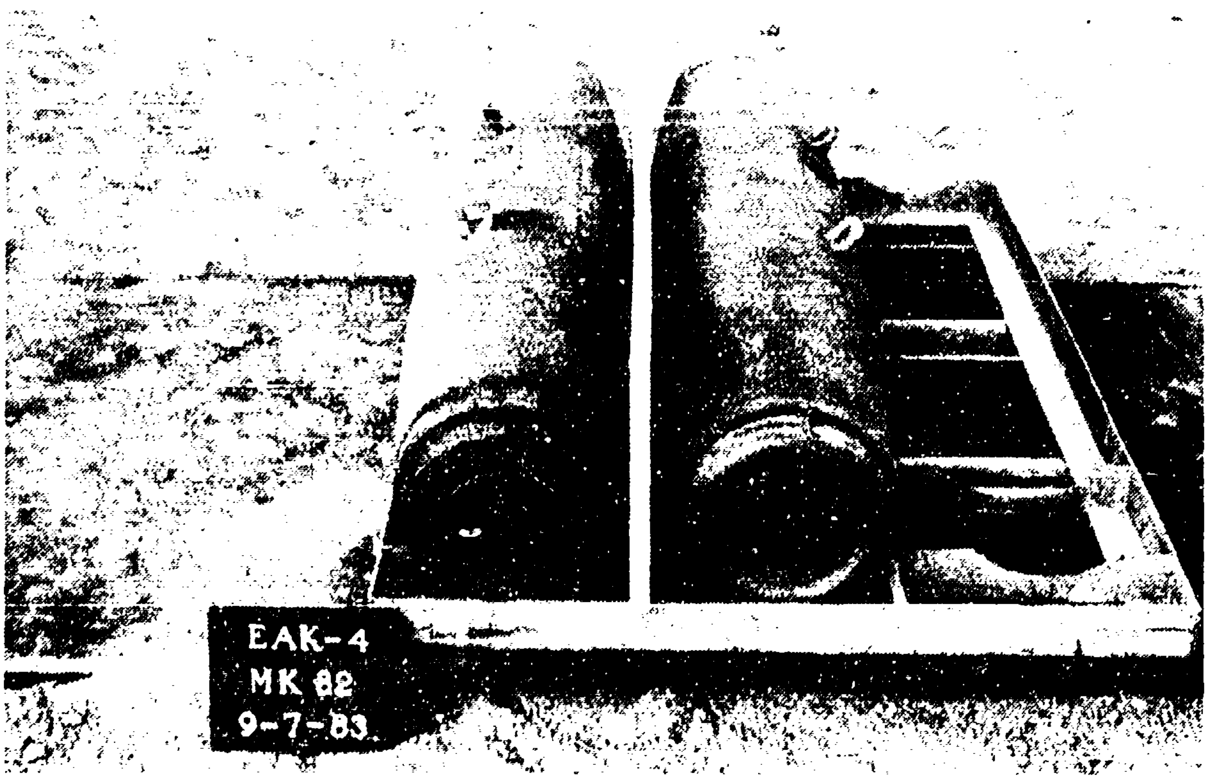


Figure [illegible] Between [illegible] Acceptors



[illegible] Acceptor

Figure 3. Witness Plate Under EAK Acceptor

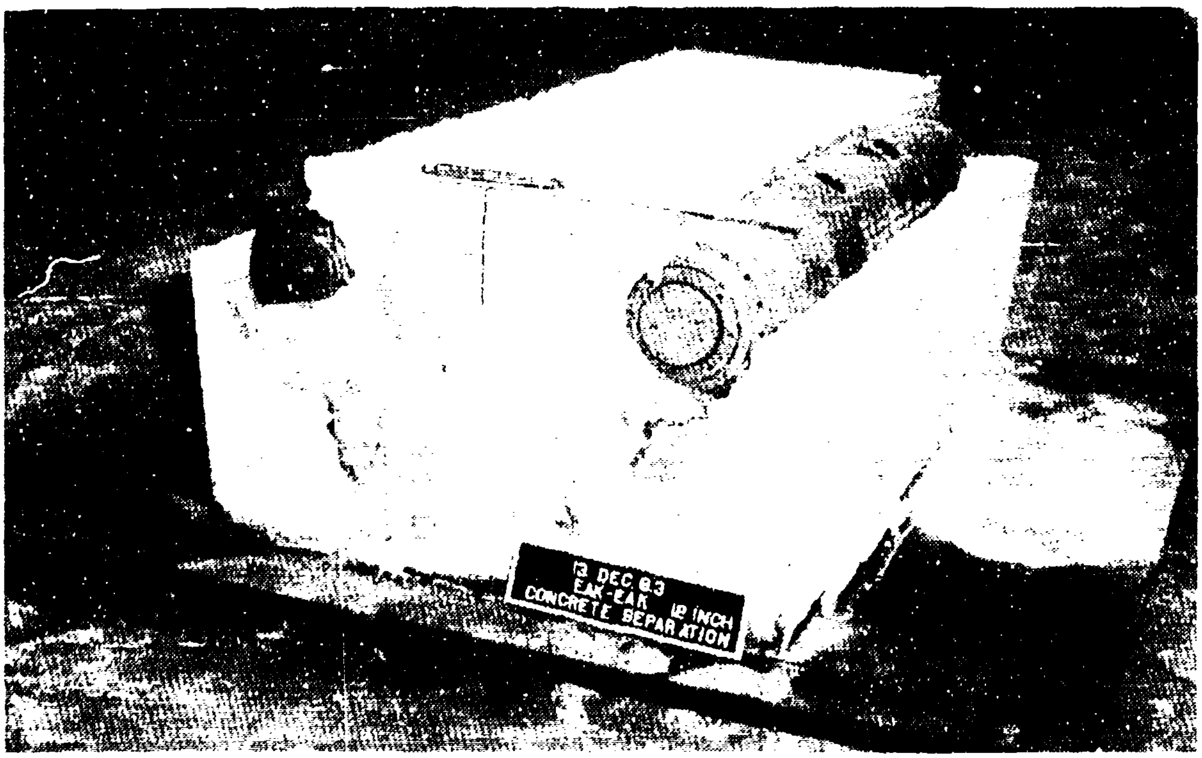


Figure 4. Experimental Set-Up for Controlled Propagation Tests

prediction of the degree of reaction in the experiment because the codes used do not calculate initiation and run up characteristics of explosives. Extensive research is required to execute this type of calculation with confidence. Rather, the approach used in the analysis of the calculations was the identification of the mechanical processes which transport energy from the donor bomb to the acceptor bomb. These processes are characterized as (a) flyer plate mode, (b) pure shock transmission, (c) mechanical distortion, and (d) fragment penetration. The primary difference between (a) and (d) is the distance between the items. As an indication of the relative efficiency of some of the processes, Table 1 lists the transmitted shock pulse through various 0.75-inch buffer materials. While air is not an efficient medium for shock propagation, it does allow large energy transfers by means of the flyer plate mode. Thus, the flyer plate mode would be characterized as very efficient when compared to shock transmission. Table 1 illustrates that peak shock pressure transmission for rounds in contact is about 60 Kbar, while rounds separated by an air space transmit almost three times the peak pressure due to impact of the donor case wall against the acceptor.

Next, a series of experiments were designed in an attempt to identify the relative importance and the critical levels associated with these processes. First, experiments were designed to determine the "second point"; that is the separation distance at which sympathetic detonation will not occur. Concrete was used to provide a conformal barrier between the donor and acceptor to insure that flyer plate or fragment impact mechanics would not be confused with shock transmission. Figure 4 illustrates the experimental set-up. Tritonal- and EAK-filled MK-82 bombs were evaluated as both donors and acceptors. Instrumentation included blast gauges, witness plates, and high speed photography (Figure 5). Tritonal-filled acceptors detonated at a spacing of

TABLE 1. RESULTS OF CALCULATED MATERIALS

Material	ρ	Co	$Z = \rho c$	Y	P	E
Air	1.225×10^{-3}	3.38×10^{4}	41	0	200×10^{9}	1.54×10^{10}
RHA	7.86	4.61×10^{5}	3.62×10^{6}	15×10^{9}	62.2×10^{9}	5.85×10^{9}
Pb	11.34	2.09×10^{5}	2.37×10^{6}	0.3×10^{9}	69.3×10^{9}	6.14×10^{9}
DU	19.05	2.48×10^{5}	4.72×10^{6}	15×10^{9}	54.0×10^{9}	5.23×10^{9}
Al	2.71	5.38×10^{5}	1.46×10^{6}	2.9×10^{9}	64.0×10^{9}	5.87×10^{9}
Ceramic	3.90	6.90×10^{5}	2.69×10^{6}	80×10^{9}	64.0×10^{9}	5.84×10^{9}
Nylon	1.14	2.29×10^{5}	2.61×10^{5}	0.5×10^{9}	70.0×10^{9}	8.44×10^{9}
Sand Contact	1.6	6.1×10^{4}	9.75×10^{9}	1.0	91.98×10^{9}	7.75×10^{9}
Sand Buried	1.6	6.1×10^{4}	9.75×10^{4}	1.0	126.32×10^{9}	9.99×10^{9}
RHA/Ceramic/ RHA	N/A	N/A	N/A	N/A	59.83×10^{9}	5.62×10^{9}

Figure 5. Instrumentation for Propagation Tests
(a) Photographic View

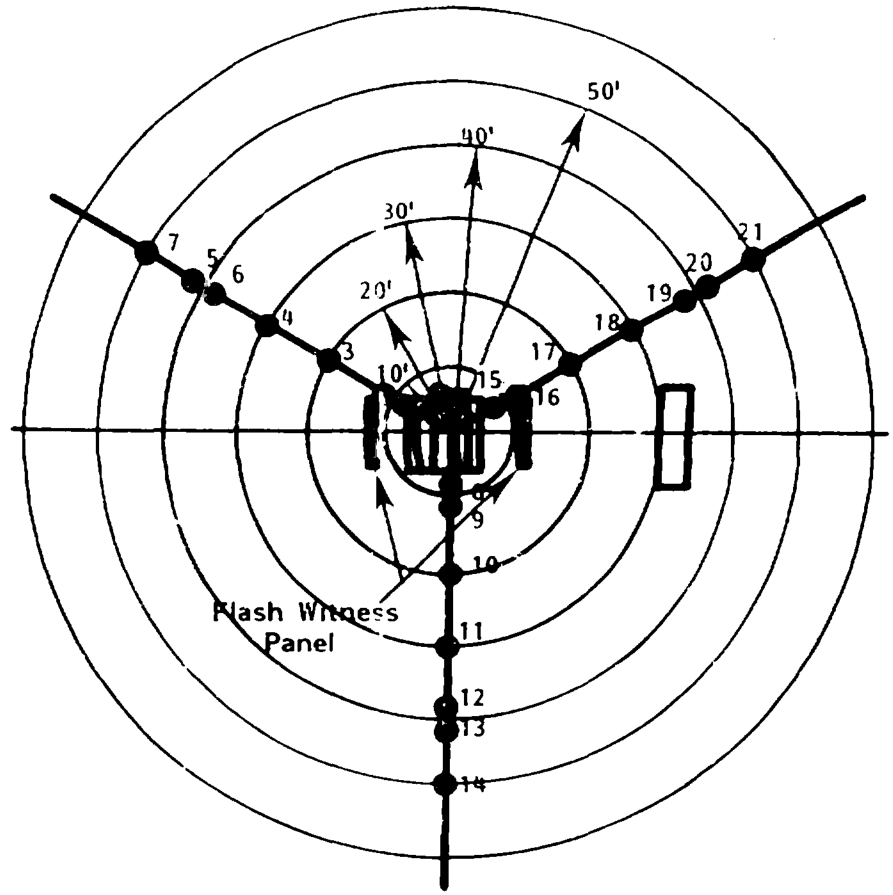


Figure 5. Instrumentation for Propagation Tests
(b) Arena Diagram

8 inches and showed essentially no explosive reaction at 12 inches. The bomb casing from the 12-inch experiment was recovered as a single piece with low pressure rupture. Acceptors filled with EAK explosive did not show a clear go/no go response. The violence of response of EAK-filled acceptors was a function of the pressure transmitted into the acceptor. Surprisingly, unreacted explosive was recovered even under conditions where the donor and acceptor were separated by only 3 inches. When a second EAK-filled acceptor in a donor/acceptor/acceptor configuration was added to the experiment, it also reacted violently leading us to conclude that these "partial detonations" produced high pressure. The principal conclusions from this series were: (1) Clarification of the unusual initiation behavior of EAK was essential; (2) MK-82 bombs are poor candidates for controlled experimental evaluation; and (3) EAK and tritonal behave markedly different when subjected to similar strength shocks.

SECTION II

SHOCK SENSITIVITY

Scaled experiments were designed to quantify the shock initiation process in EAK and tritonal and to evaluate materials which could be used as a barrier between the acceptor and donor. Figure 6 illustrates the hardware designed to measure shock sensitivity. It is basically a large scale gap test in which both donor and acceptor are encased in an 8-inch outside diameter by 0.5-inch wall steel pipe. Composition B donors, 8 inches long, were used to produce the transmitted shock. Acceptors were instrumented with time of arrival pins on 2-inch centers to measure shock velocity as a function of position in the acceptor. The completed test assembly was mounted on a 1-inch rolled homogeneous armor plate which served as a fragment witness. Plexiglas®, of varying thicknesses, and steel endplates were used to control

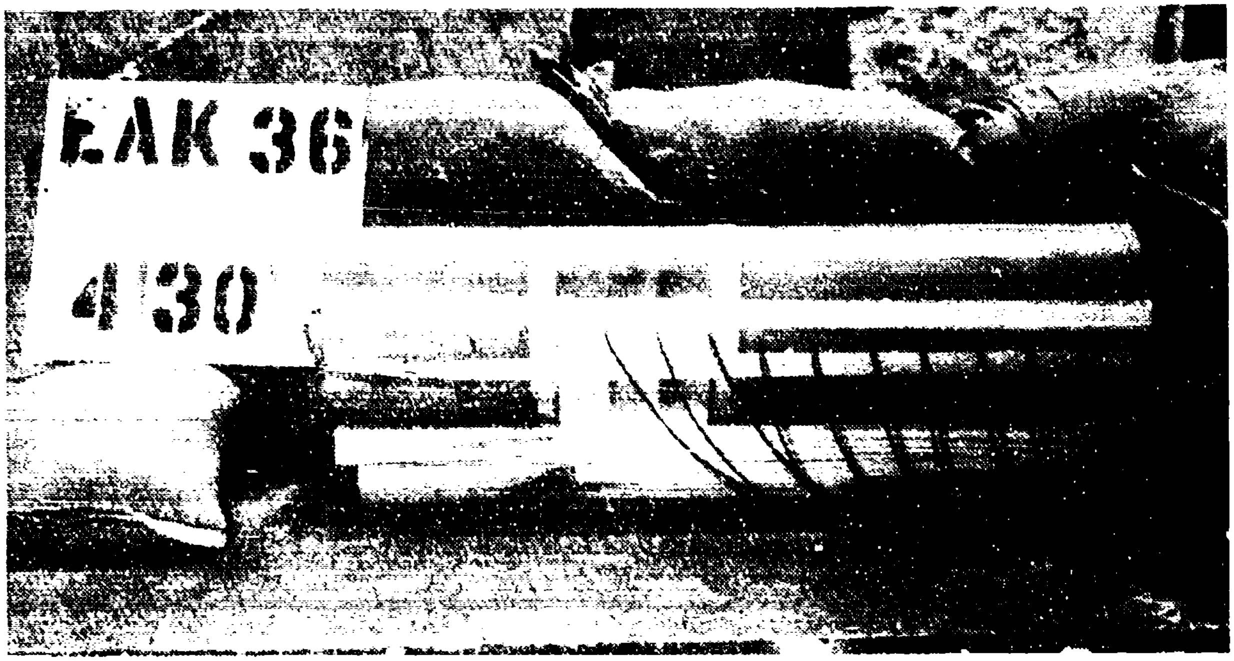


Figure 6. Shock Sensitivity Set-Up Composition B Donor on Left Plexiglas Gap, and Acceptor Explosive

the shock strength transmitted into the acceptor. Baseline experiments were conducted using concrete separator plate to establish comparability with the MK-82 experiments. Calculations were performed to describe input pressure as a function of gap thickness (Figure 8) and the pressure position profile of the transmitted shock (Figure 9) as a function of distance from the donor/Plexiglas® interface. The calculation to determine the pressure position profile was performed to enable clarification of the function of endplates in the role as shock attenuators. As can be seen, without endplates the pressure pulse decays rapidly until approximately 4 inches of Plexiglas® have been traversed, at which time an inflection point is reached and the decay is moderated. However, with endplates, the pressure decays much slower and, if an inflection poin is reached, it occurs between zero and one inch. Also, the positive pulse duration of the transmitted pulse is longer with endplates than without endplates. To verify the predictive ability of the model, the standard Naval Ordnance Laboratory (NOL) gap test was also calculated. Figure 9 shows that our computer codes reproduce the pressure/distance profile for NOL gap test. Figure 6 shows the assembled experiment where donor and acceptor are separated by two 1/2-inch-thick endplates and 6 inches of Plexiglas®. The unusually large size of this gap test was selected to insure that experiments were well above the failure diameter of EAK and to better simulate the long duration shocks characteristic of sympathetic detonation in MK-82 bombs.

Table 2 lists the go/no go conditions for EAK and tritonal. EAK is slightly less sensitive to shock than tritonal since the go/no go spacing corresponds to about 14 Kbar. The go/no go pressure for tritonal is greater than 12 Kbar and less than 14 Kbar. These initiation pressures are far below the published values for tritonal (approximately 30 to 40 Kbar). Clearly

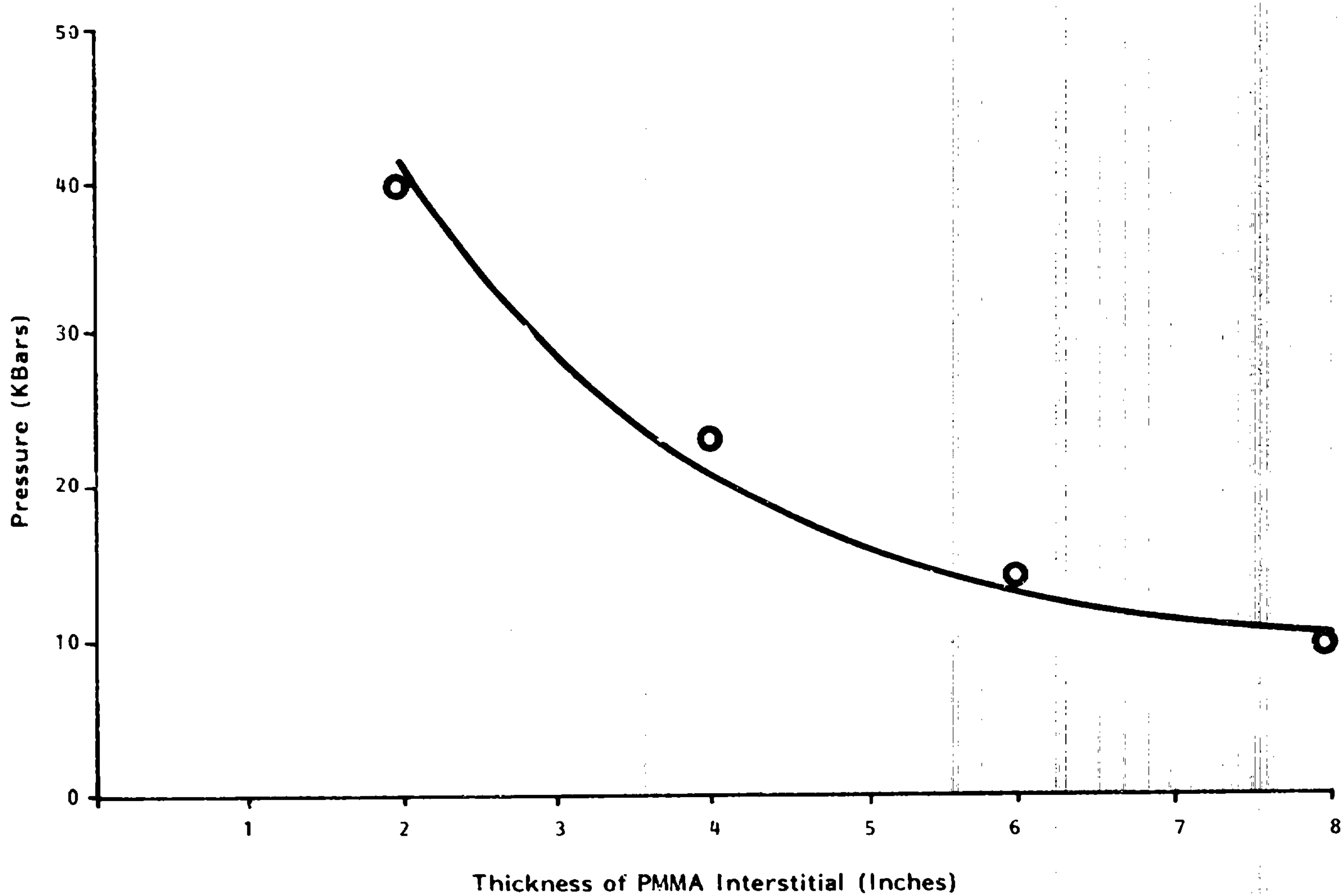


Figure 7. Centerline Pressure Pulse of EAK Acceptor ($\frac{1}{2}$" Into EAK) (Curve Calculated From $P={}^{K}/_{R}$)

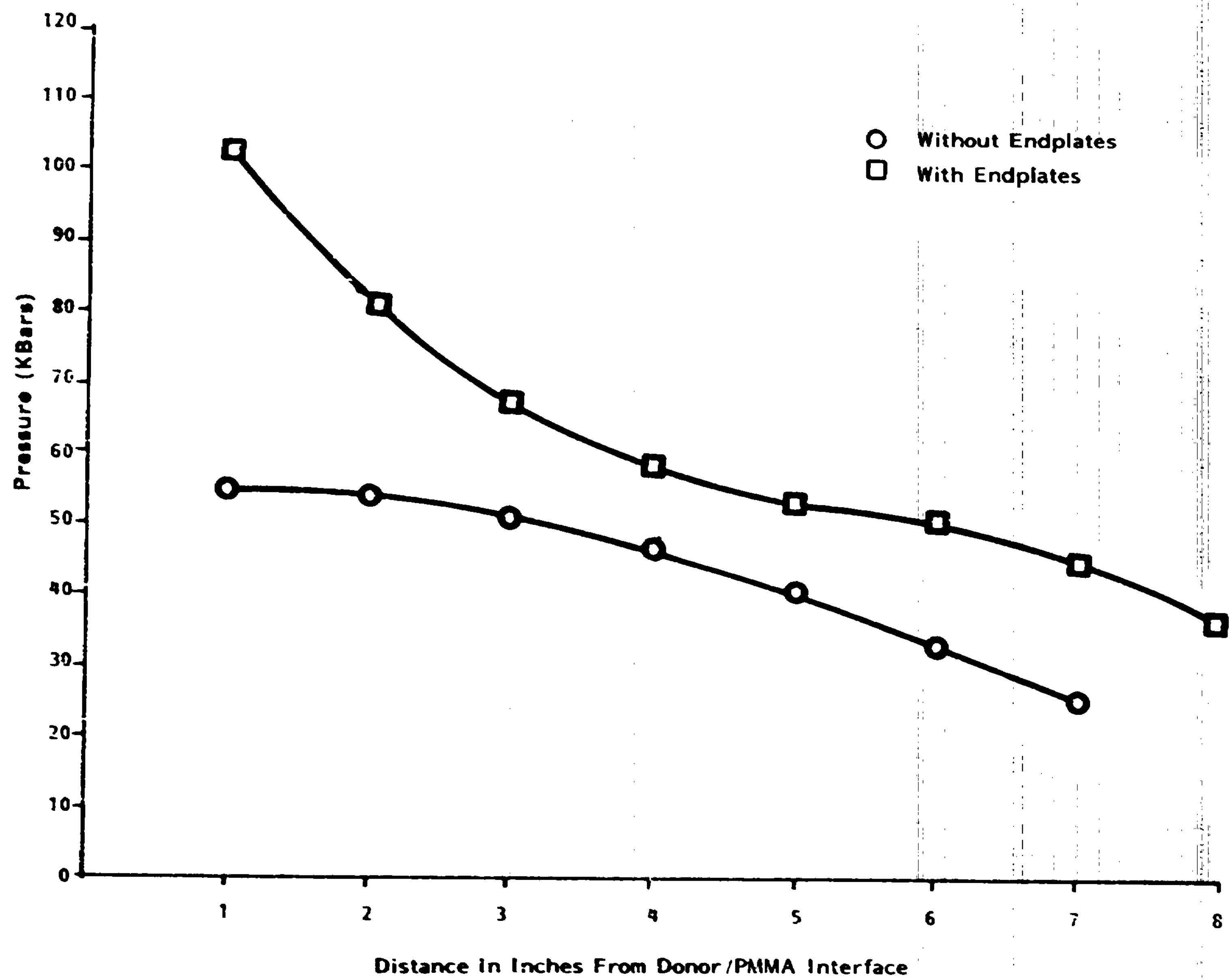


Figure 8. Influence of Endplates

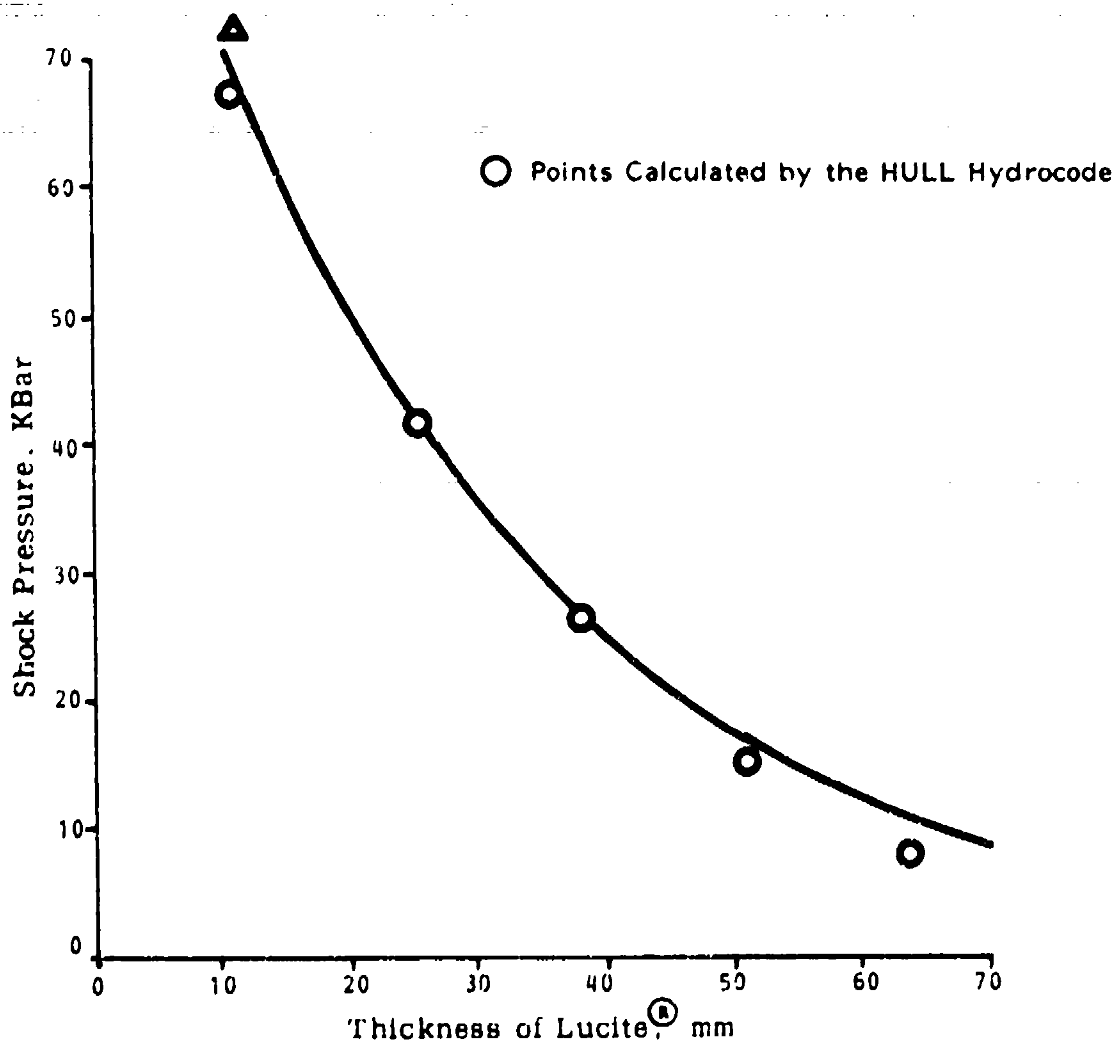


Figure 9. Shock Wave Pressure at the End of the Lucite® Gap in the NOL Gap Test

TABLE 2. GO/NO GO RESPONSE FOR VARIOUS EXPLOSIVES AT FIVE DIFFERENT THICKNESSES OF PLEXIGLAS® IN 8-INCH-DIAMETER GAP TEST

THICKNESS OF PLEXIGLAS®

2-inch	4-inch	6-inch	7-inch	8-inch
EAK 42-X	EAK 46-X	EAK 42-?	EAK 42-O	EAK 46-O
EAK 46-X	EAK/NQ-X	EAK 46-X	EAK 46-O	
EAK/NQ-X	TRI-X	EAK 50-X	EAK/NQ-O	
		EAK/NQ-O	TRI-O	
		TRI-X		

X - GO

O - NO GO

both amplitude and duration are important factors in initiation to detonation. Figure 10 shows shock velocity as a function of position in the EAK- and tritonal-filled acceptors. The very slow increase in velocity down the length of the cylinder for EAK was characteristic of this formula even when strong shocks were used as the initiator. On the other hand, tritonal quickly transitions to 6.9 km/sec.

It is believed that this difference in transition behavior accounts for variable reaction violence we observed in full-scale MK-82 bomb tests. The bomb diameter is small relative to the distance required to establish a high velocity detonation in EAK. Thus, increasing the input shock serves to increase the reaction velocity across the bomb and subsequent violence of the reaction. This conclusion is, in fact, supported by the fragment witness observed in the large scale gap tests. It suggests that EAK-filled rounds would not support sympathetic detonation as long as the very high pressures associated with case wall impact are not allowed to occur.

SECTION III

BARRIER DESIGN

Given that the shock sensitivity of the explosive has been defined, the second aspect of suppressing sympathetic detonation is that of attenuating or reducing transmitted shock and deflecting case wall fragments. Barriers between bombs are the most reasonable approach. Again the computer was used to evaluate a variety of materials. Figure 11 illustrates the computational layout, and Figure 12 gives the results. The calculation predicts peak pressure transmitted from a Composition B donor to the explosive fill in the acceptor. Figure 12 is a plot of peak pressures versus gap thickness recorded at Station 1 (see Figure 11). The length of the PMMA diverter remained constant (4 inches). The 0.5- and 1.0-inch airgaps were modeled between the

TABLE 3. ACCEPTOR RESPONSE TO VARIOUS BARRIER DESIGNS

TEST CONFIGURATION SUMMARY

TEST	DIVERTER t x W	DIVERTER Material	α (deg)	α′ (deg)	RESULTS
EAK 14	2" x 8"	Plexiglas®	14.48	14.0	NO GO
EAK 15	2" x 6"	Plexiglas®	16.60	14.0	NO GO
EAK 16	2" x 5"	Plexiglas®	17.92	14.0	NO GO
EAK 17	2" x 4"	Plexiglas®	19.47	14.0	NO GO
EAK 18	4" x 2"	Plexiglas®	23.58	26.57	GO
EAK 19	2 1/4" x 4"	Yellow Pine	19.47	15.71	NO GO
EAK 20	2" x 4"	Phenolic	19.47	14.0	NO GO
EAK 21	1. 3" x 1" 2. 1" x 1" 3. 3" x 1"	1020 Steel "H" 1. + 2. + 3.	21.32	20.56	NO GO

α = Included half-angle

α′ = Protection half-angle

Reference Figure 13.

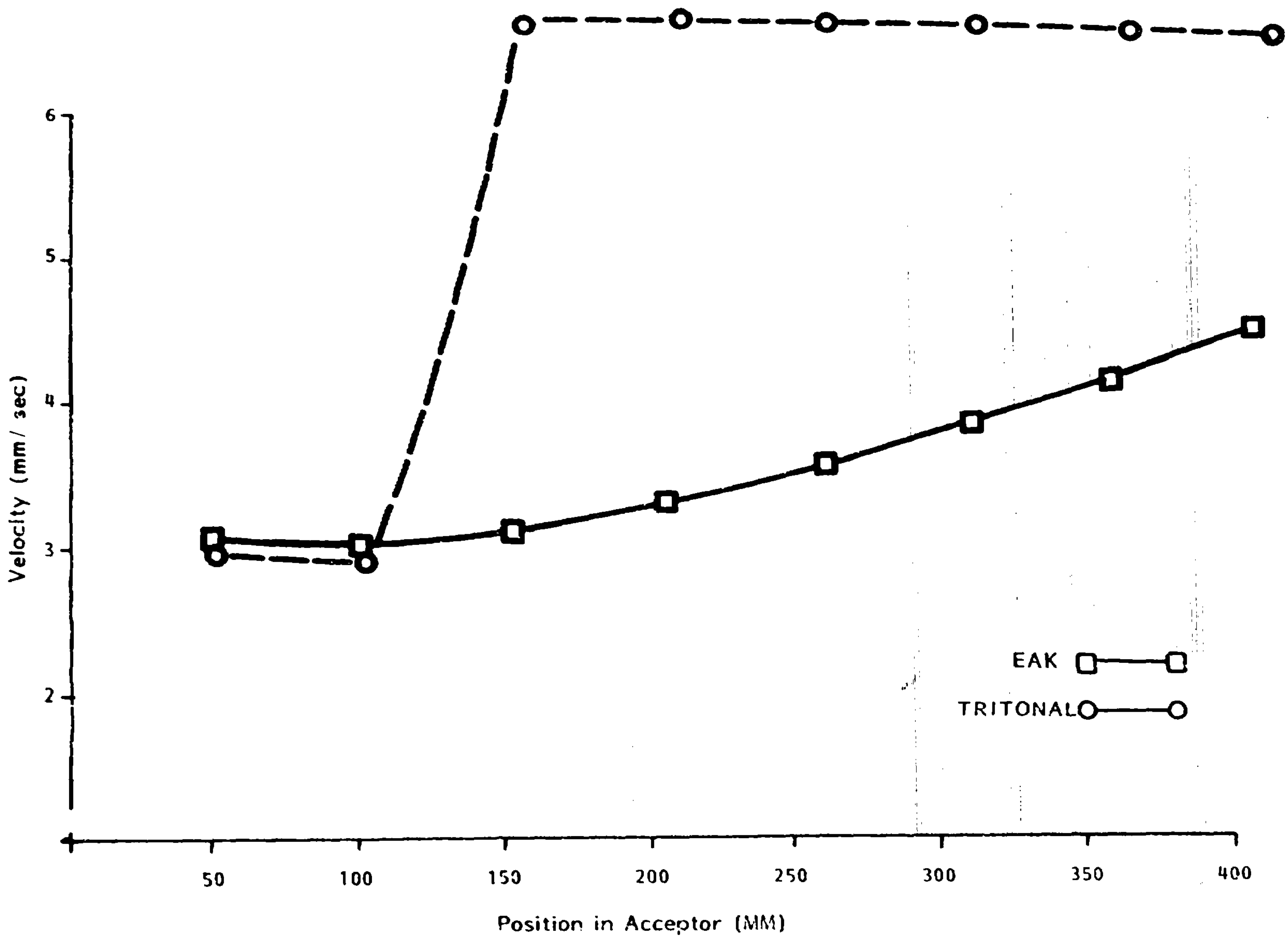


Figure 10. Shock Velocity for EAK and Tritonal With 14-KBar Input Pressure

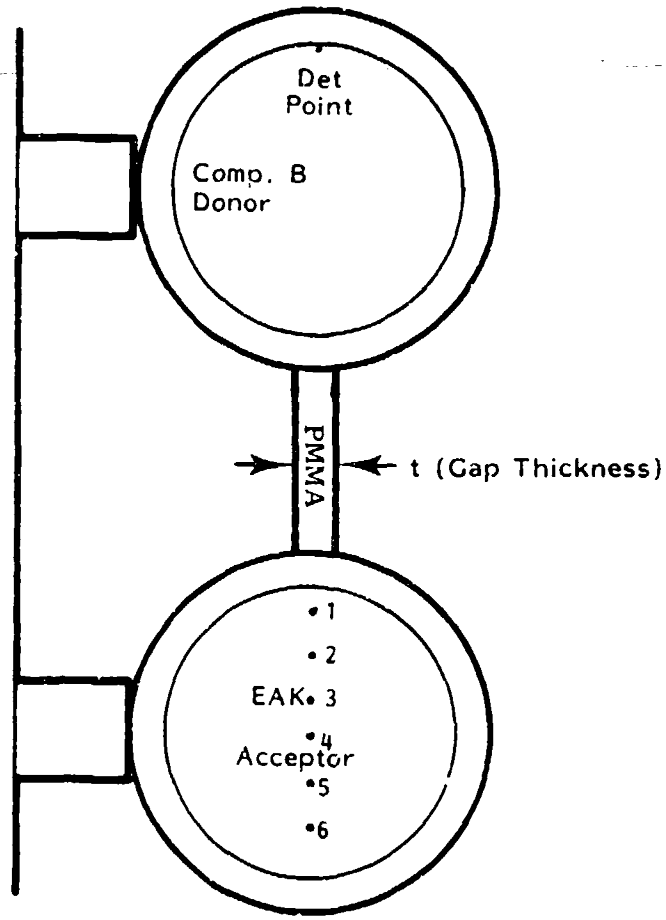


Figure 11. Computational Set-Up for Barrier Tests

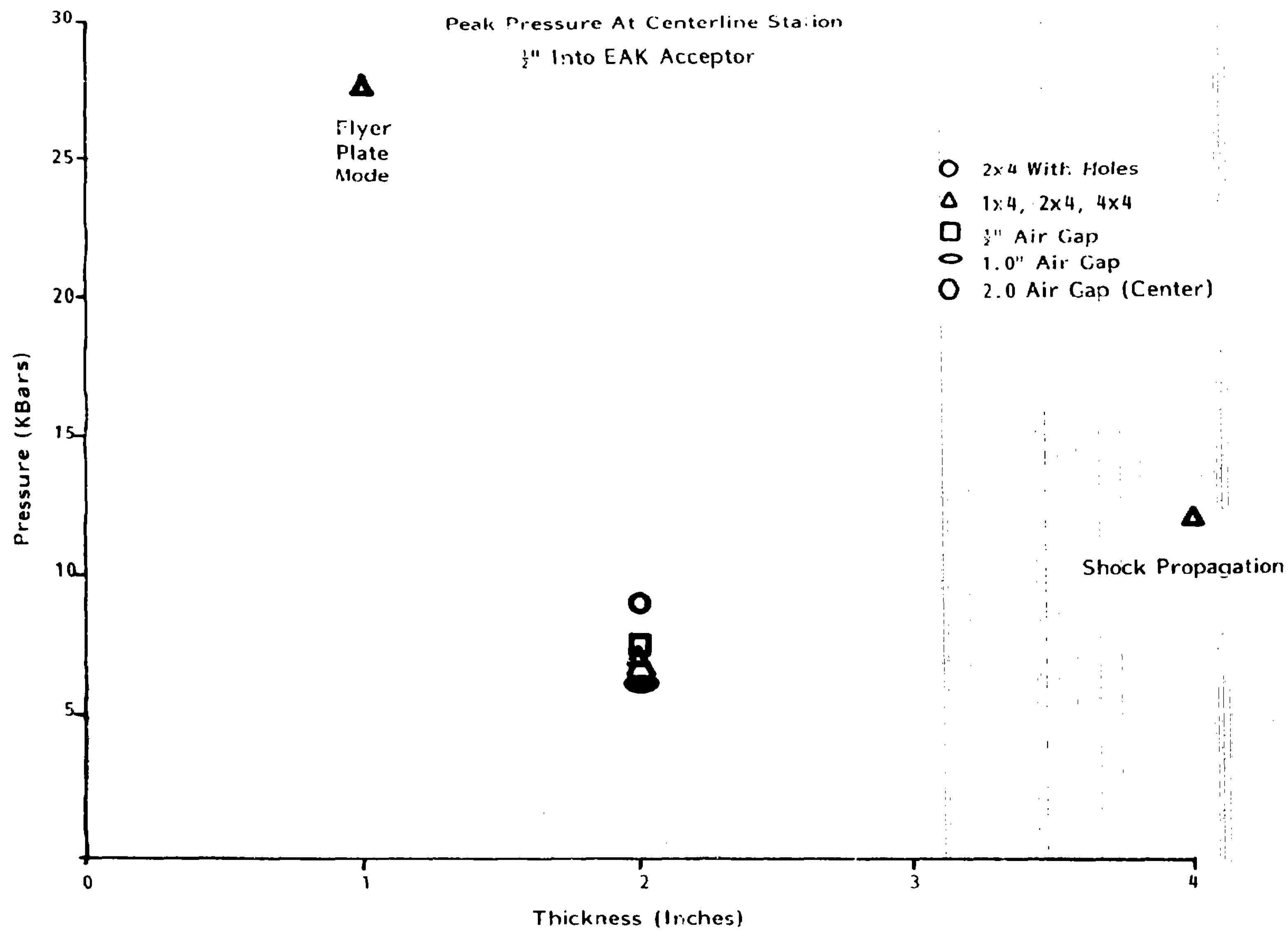


Figure 12. Peak Pressure Recorded at Station 1 in Figure 11 for Various Barrier Designs

diverter and acceptor/donor interface. The 2.0 airgap was modeled at the center of the PMMA diverter. The plot indicates that the 2 x 4 diverter allows the least combined flyer plate/shock transmission mode energy transfer to the acceptor. A number of materials were simulated using selection criteria such as density, sound speed, and strength. Differences between materials were not dramatic. Thus, for the experimental portion of this study plastic, wood, and steel were selected for the barriers. These were selected on the basis of cost, availability, and range density. Figure 13 shows the experimental design. The explosives were contained in the same type of cylinder used for the shock sensitivity tests except that the donor charge was now the same length as the acceptor charges. Again, Composition B was used in the donor. Figure 14 is a typical experimental set-up used in this test series. The width of the barrier determines the transmitted shock from donor to acceptor while the thickness provides protection from donor case fragments; minimizing the thickness consistent with sufficient fragment protection introduces the additional mechanics of shock attenuation down a thin membrane. Table 3 lists the response of acceptors to various barriers evaluated in this series. Figures 15 through 17 illustrate pre- and post-shot conditions of the acceptors.

Our results indicate that the membrane/diverter approach provides sufficient attenuation such that we can suppress sympathetic detonation using barriers approximately 1/3 to 1/2 the diameter of the round for explosives having the sensitivity of EAK and tritonal. These compare to 1 to 1.2 diameter of concrete demonstrated in the MK-82 experiments. Four-inch barriers of phenolic and Plexiglas® were effective as was the 3-inch steel "I" beam. We believe that considerable weight reduction could be achieved with the steel barrier. Fragment deflection can be achieved by insuring that the angle subtended by two lines emanating from the center of the donor to the

Typical Test Set-Up

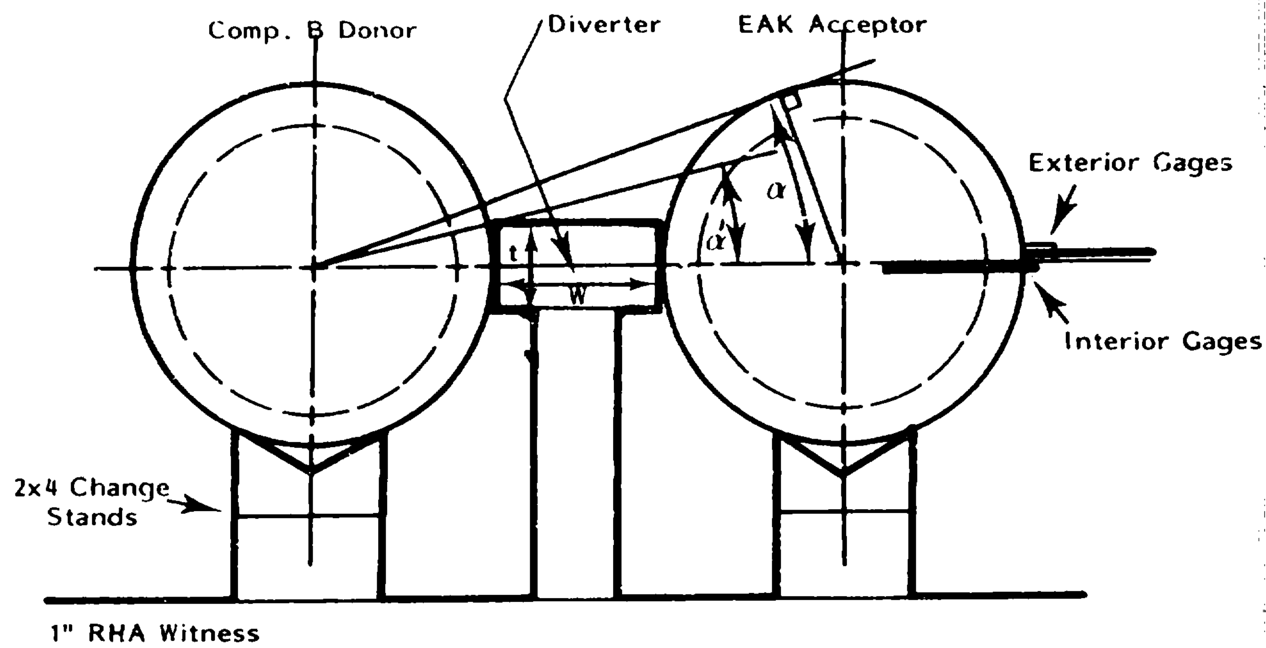


Figure 13. Experimental Design for Engineering Scale Sympathetic Detonation Tests

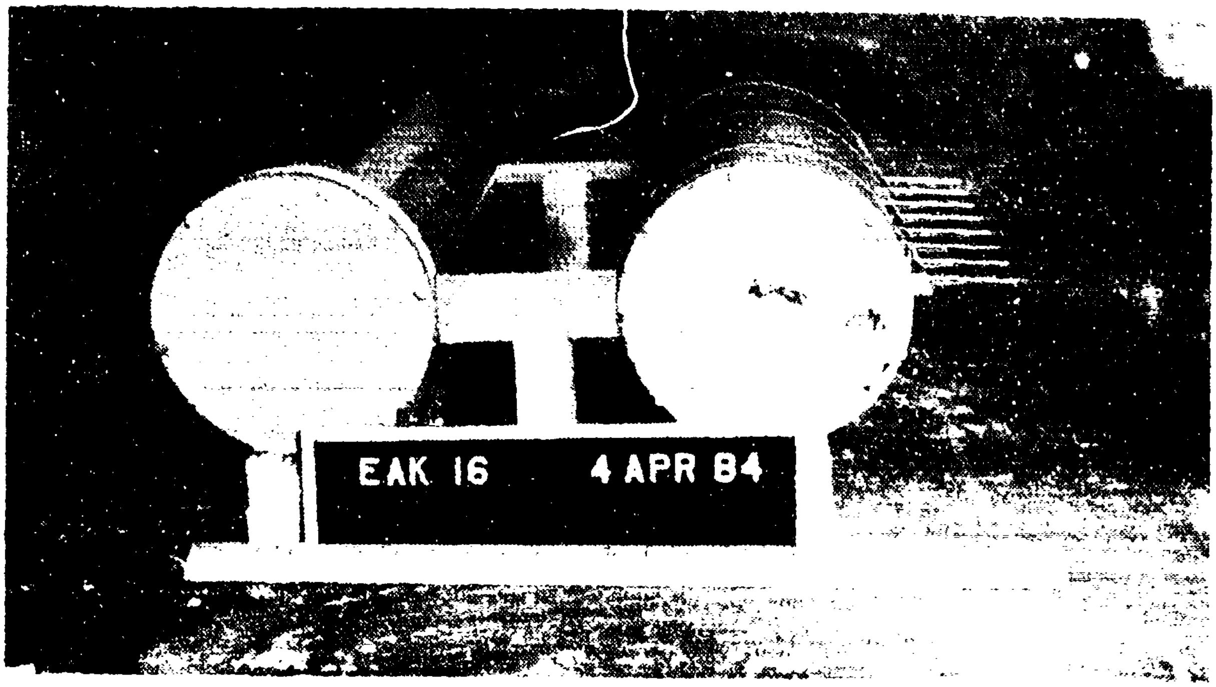


Figure 14. Hardware Used in Engineering Scale Sympathetic Detonation Tests

Figure 15. Experimental Set-Up Using Flexible [illegible]

Figure 16. Recovered Explosive

Figure 17. Deformation of Acceptor Case

upper and lower edges of the barrier is greater than the angle, subtended by two lines also emanating from the center of the donor and being tangent to the acceptor (Figure 13).

SECTION IV

CONCLUSIONS

There are two basic approaches to suppression of sympathetic detonation. Minimizing the shock sensitivity of the explosive to long duration pressure will obviously reduce interround separation distances. However, given that the explosive sensitivity is fixed, then much can be gained through the use of simple barriers placed between the rounds. We have devised calculational methods for predicting shock transmission; experimental methods have been developed to characterize explosive shock sensitivity and observe the response of acceptors to barriers. We have shown that both EAK and tritonal can be initiated to detonation with relatively low pressure shocks of long durations. And we have shown that to be an effective barrier between the donor and acceptor, the material must attenuate shock and deflect fragments. Future actions will concentrate on refining the design of barriers to minimize weight, volume, and cost.